Resistor and Capacitor Time Constant Measuring Instrument Using Arduino UNO

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Article Info

ABSTRACT

The most interesting problem to be discussed in electrical physics is one-way electric circuits. In this work, the researchers constructed an experimental setup for determining the time constant of DC resistors and capacitors using the open-source Arduino UNO hardware platform. Arduino UNO was a signal generator for data collection systems and a simple signal visualization instrument. Experiments were carried out using an analog oscilloscope combined with theoretical calculations. The results show that, on a spreadsheet, the data processing and fitting of the curves for the six Resistor and Capacitor test sets yielded values determined by the component tolerances. The researchers believe that the design of this equipment and software demonstrates the recommended suitability, making it flexible for use in teaching and learning in laboratory contexts.

INTRODUCTION

Electrical physics in direct current electric components has become an interesting subject to discuss to investigate the physical phenomena in electrical components (Demarteau et al., 2016). The measurement of the time constant of resistors and capacitors (RC) is one of the important methods in the testing and analysis of electronic circuits (Prayogi et al., 2021). The RC time constant refers to the time it takes for the electric charge in the capacitor or the electric current through the resistor to reach approximately 63.2% of its final value (Sands, 2021). Developing a resistor and capacitor time constant measuring instrument using the Arduino UNO is a popular and efficient approach to automating the measurement process (Gupta & Agarwal, 2017). Developing a resistor and capacitor time constant measurement instrument using the Arduino UNO provides several benefits (Colinge & Colinge, 2002). First, using Arduino UNO makes the RC time constant measurement process easier and more automated, reducing human error and increasing measurement accuracy (Demirel, 2021). In addition, using the Arduino UNO, the researchers can easily program and adjust the input signal according to the test needs. This meter is also flexible and can be used for various sizes of resistors and capacitors.

The development of resistor and capacitor time constant measuring instruments using the Arduino UNO has become an active research area in the measurement and characterization of electronic circuits. The Arduino UNO has become a popular and affordable platform for developing reliable, easy-to-use measuring instruments. Several

previous projects and studies have implemented this method with various approaches and additional features (Kurniawan et al., 2019). Several studies have focused on developing techniques and methods to improve the measurement accuracy of the time constant of resistors and capacitors. The studies involved careful calibration, precise components, and circuits that minimize measurement error (Prayogi et al., 2022b).

Furthermore, several projects have integrated resistor and capacitor time constant measuring instruments using the Arduino UNO with an intuitive user interface, including LCDs, control knobs, and the ability to save and load measurement data (Roslina et al., 2022). Several studies have focused on developing data processing algorithms to produce more accurate and stable measurement results using filtration, interpolation, or regression techniques to analyze the timing data obtained from the Arduino UNO (Wu et al., 2021). Although developing time-constant resistors and capacitors using the Arduino UNO has progressed, some areas can be improved and focused for future research (Logan et al., 2020). Through further research and development, it is hoped that the development of a resistor and capacitor time constant measuring instrument using the Arduino UNO can continue to improve its accuracy, speed, and functionality features (Talwariya et al., 2020) to better support the development and characterization of electronic circuits (Solem et al., 2015).

In developing this instrument, the researchers hope to demonstrate that setting up a feasible and affordable experimental treatment allows for more active students' participation by measuring the time constant of an RC circuit, a well-known physical system. The researchers outlined the entire trial development process using the Arduino open-source hardware platform (Serhane et al., 2019). Using this platform and basic programming, The researchers can install square wave generators, data collection

systems (DACs), and real-time signal visualization instruments (Santoso & Munawanto, 2020). The researchers also use an analog oscilloscope to observe the charge-discharge cycle of the capacitor. This instrument is a great resource for students to better understand procedures in real-time.

Thus, this study aimed to develop a resistor and capacitor time constant measuring instrument using Arduino UNO.

METHODS

This study employed the Design-based Research (DBR) method. The DBR method is expected to create the latest innovations in learning media that can be used in the teaching and learning process (Hess & Greer, 2016). In this study, only three stages were used. They are the analysis, design, and development stages. This research type of data is descriptive data to describe the validity level of the learning media (Kurniawan et al., 2019). The type of research was qualitative-quantitative, assisted by instruments to obtain all the necessary data.

The researchers are simply addressing the aspects of capacitor theory relevant to the charge-discharge cycle as the major focus of this work. The theory of capacitors is well-documented in most undergraduate physics textbooks (Singh & Shougaijam, 2022). The fundamental RC circuit in Figure 1 includes a switch and a voltage source. Current will flow through the circuit when the researchers close the switch, provided the capacitor is not charged.
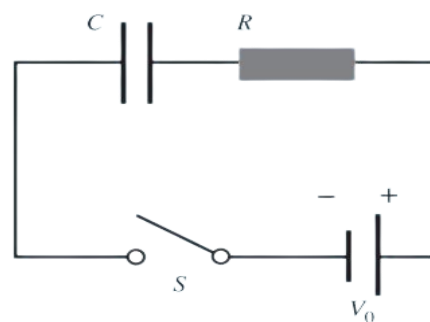
Figure 1. Illustrates the fundamental circuit with a switch S, a voltage source Vo, a resistor R, and a capacitor C.

For this work, the researchers used live experimental instruments of electrical resistors, electrolytic capacitors, breadboards, Arduino Uno R3, and an analog oscilloscope, as the researchers will show in Figure 2. On a portable 64-bit Linux PC with typical specs, the Arduino IDE was installed (2.5 GHz dual-core processor with 4 GB RAM and 300 GB Hard drive). The ability to investigate circuits and see the mechanics of a capacitor's charge/discharge cycle is provided by an oscilloscope, albeit it is not necessary (Checchetti & Fantini, 2015). The Arduino can partially replace the oscilloscope with enough programming.

We must specify the components of our experimental apparatus a square wave generator, a data gathering system, and a signal visualization instrument keeping in mind the ultimate objective of this work, the measurement of the time constant of an RC circuit (Hamdani et al., 2022). The researchers demonstrate how to construct and combine these blocks in the following sections. Data processing processes are not an issue for us currently (Suyanto et al., 2021).

Figure 2. The Atmega328P microcontroller drives the Arduino UNO R3 hardware platform.

RESULTS AND DISCUSSION
The Square Wave Generator

The researchers can create a straightforward square wave generator using digital pins on Arduino. The researchers can generate a square wave with sufficient accuracy for this experiment by placing one of the pins in the high state for a period and

then in the low form for the same period. As viewed in the UNO, the code is listed in Figure 3, with the instruction pin Mode (digital OUT, OUTPUT). The researchers designate digital pin 11 (which is defined in the variable digital OUT) as an output pin, and in the main loop, the researchers cycle that pin's state between High (+5 V) and LOW (0 V).
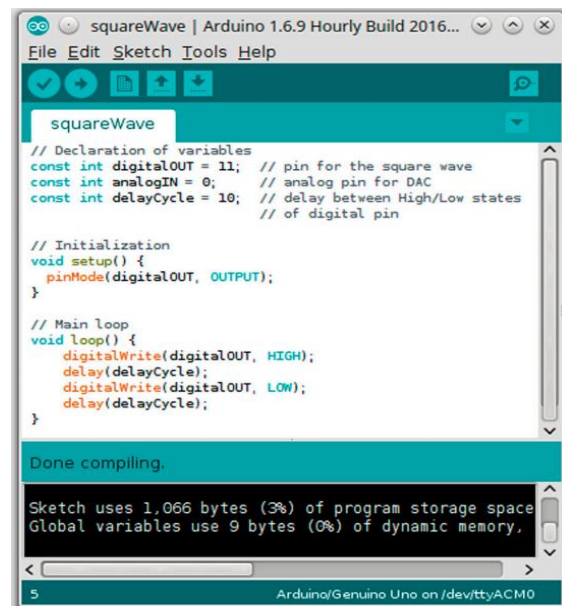

Figure 3. Square wave generator that has been IDE-compiled.

The length of time (in milliseconds) that the plug spends in each state is controlled by the variable delay cycle (Rismawan & Toifur, 2018). To test the code, the researchers utilized an RC circuit with R = 390 Ω and C = 22 F. Figures 4 and 5 show the setup and an oscilloscope visualization, respectively. For this experiment, the signal's stability is sufficient.
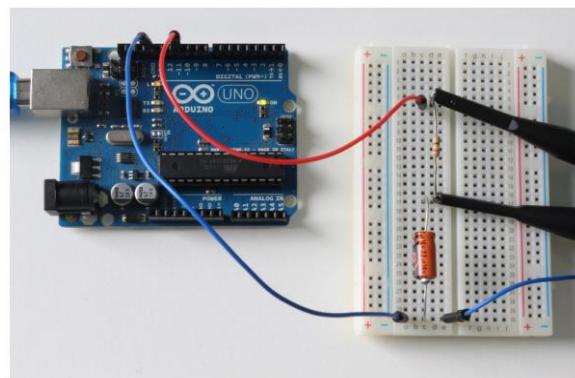

Figure 4. The Generator for Square Waves.

We may perform some calculations at this experiment stage to compare the theory with our findings. The circuit in Figure 4 had R = 390 Ω (±5%) and C = 22µF (±20%), τ = RC = 8.6 ms, with Vo≈4.8 V (measured on the oscilloscope vertical scale). The researchers have, after 15 ms (measured on the oscilloscope horizontal scale), Vc ≈ 4.0 V. Considering the tolerance of the components, researchers can define τ_{max} ≈ 10.9 ms and τ_{min} ≈ 6.6 ms, which gives 3.6V ⩽ (Vc 15) ms ⩽ 4.3 V, using again. The voltage of the capacitor after 15ms is Vc⩽ 4.4 V, as measured on the oscilloscope within an error inferior to 0.4V (the value of the smallest divisions of the vertical scale), which is in good agreement with our calculation (Prayogi & Marzuki, 2022).
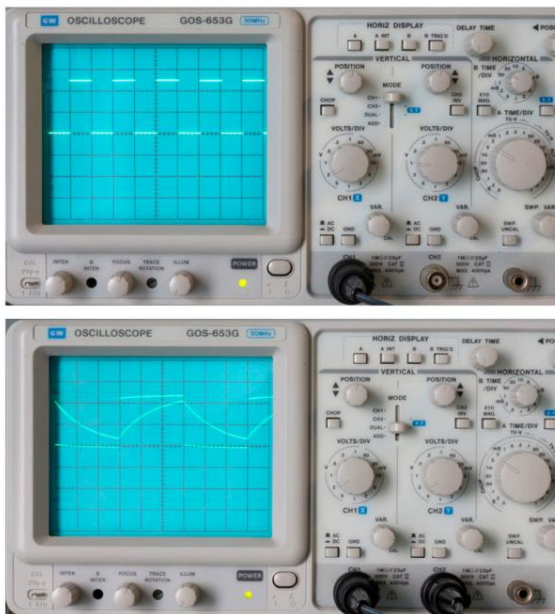
Figure 5. The Analog Oscilloscope's Signal Visualization.

An analog oscilloscope is a fantastic instrument for training measurement by observing visual displays in laboratory activities (Susilawati et al., 2021). Given that the components have tolerances related to the nominal values, comparing the observed values with the theoretical predictions is crucial.

Arduino data collection and visualization

The new instrument, a serial plotter accessible from the Instruments menu, has been added to the Arduino UNO. It generates a graphical representation of the values sent to the serial port (Qureshi & Ünlü, 2020). the researchers can replace the oscilloscope with this new functionality and visualize the charge-discharge cycle. To achieve this, the Arduino serves as a DAC system and, as before, a signal generator.

According to Figure 6, the Arduino's analog pin A_0 is used to measure the voltage at the capacitor's positive terminal. The serial plotter can monitor both signals, square wave, and capacitor voltage, as shown in Figure 7. The window has a fixed 500-point horizontal axis, and the value n is displayed on the diagram each time the code executes a Serial (Saphet et al., 2017). print(n) or Serial. print ln(n) command. This instrument is quite helpful for the qualitative monitoring of signals, even though the researchers do not have an explicit time scale (Zhang et al., 2022). The capacitor's charge-discharge cycle may be readily seen in the square wave signal.
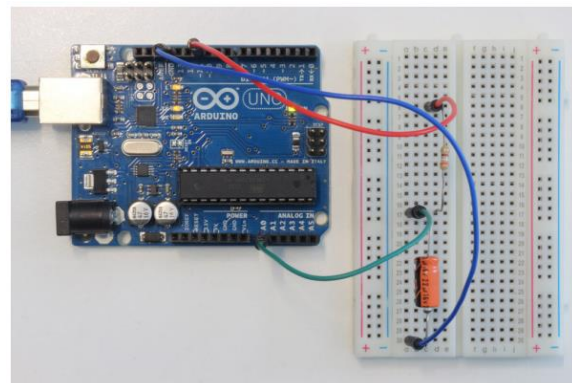
Figure 6. Square wave generator with DAQ apparatus for τ measurement

A more complex program than the one shown in Figure 3 is required to configure the Arduino as a DAQ. To read the voltage at the capacitor's positive terminal when it charges and discharges, respectively, the main loop repeatedly invokes the two operations' charge and discharge (Alexeev et al., 2019). Both functions transmit voltage values to the serial port, enabling the serial plotter instrument to display the visuals.
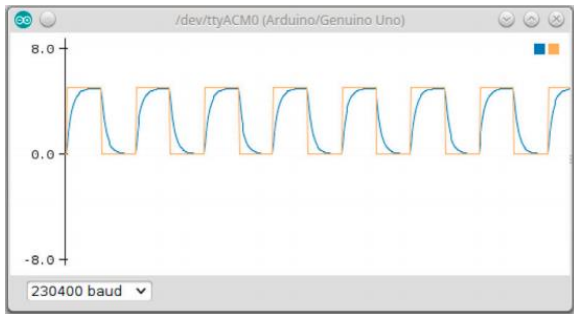
Figure 7. Graphical window created by the serial plotter instrument available on the Arduino UNO

The component values must be considered to properly visualize the charge-discharge cycle, and the program's sampling frequency must be adjusted correspondingly (Castro et al., 2014). After four cycles of charging, the capacitor will have received 98% of the circuit's provided voltage. To accurately depict the charge-discharge cycle, the researchers multiply the sample period by that number (Kurniawan et al., 2019). The horizontal axis of the graphic window has a fixed number of points, and the researchers wish to see at least two full cycles.

The two settings in Arduino DAQ that need to be changed are delay Read and dim. The former determines the interval between reads in milliseconds, and the latter the number of samples (Prayogi et al., 2022). The researchers need a read x dim 4τ delay for each circuit. Table 1 contains the values of these variables chosen for each circuit and utilized to create the images in Figure 7.

Table 1. The number of reads (N) and time between reads (Δt_r) for each circuit.

R (Ω)	C (μF)	τ (ms)	N	Δt_r (ms)
390	22	8.6	34	1
660	1000	660	132	20

### The DAC system for τ measurement

We wish to fit experimental values of the capacitor voltage to the time constant (2). The program receives the capacitor voltage from analog pin A_0 during the discharge phase and saves it in the array Vr, of size dim, to do efficient sampling. The function print Data is delivered to the serial port once the function's charge and discharge have been called (Hikino & Adachi, 2004). The

researchers can see the readings using the Serial Monitor instrument included with the UNO. Now that the researchers know the time constant from the nominal values of the components, it is crucial to set the variable's delay Read and delay Cycle with appropriate values τ_n = RC.

We must relate each voltage measurement to a specific moment since it involves the time variable. The researchers use the Arduino function *millis*, which gives us the milliseconds since the board started executing the program. When the researchers read a voltage, the researchers also read the time using the *millis* function, storing the result in an array of dim sizes (Hillier et al., 2020). The researchers establish the time scale inside the print Data method by deducting the beginning *millis* count from each *tdaq* value (Syafutri et al., 2020). Additionally, the print Data function multiplies each reading from analog pin A0's range of 0 to 1023 by the appropriate scale factor to produce a voltage value of 0 to 5V. (variable scale) (Dimitrakellis et al., 2016).

The application automatically does the fit. Figure 8 shows the visuals with the experimental findings for each circuit and the fit equation. f (x) = α exp (-β, x). The researchers can calculate an experimental time constant for the circuit using the exponent coefficient of the fit function τ_e = 1/β. The nominal values of the components define the nominal time constant, τ_n = RC, and their tolerances (R ±5% ±, C 20%) define a minimum and a maximum time constant, τ_{min} and τ_{max}, respectively.
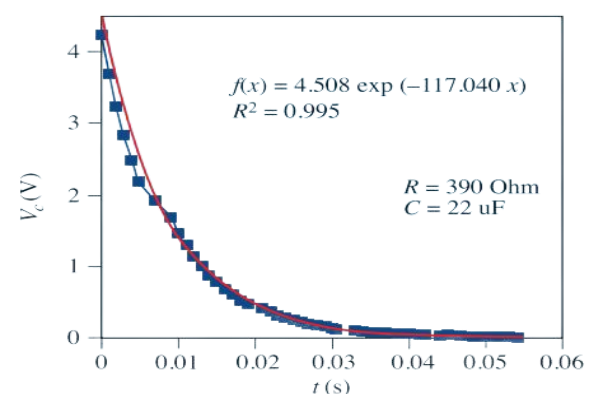
Figure 8. Capacitor voltage during discharge (blue line with squares) and exponential fit (red line)

Despite being straightforward, the apparatus produces accurate results when determining time constants (Handhika et al., 2018). For the circuits tested, the researchers could determine values of τ with a relative error as low as $\approx 0.2\%$ and, in the worst case, a relative error of $\approx 15\%$. The experimental values are all within the interval $[\tau_{min}, \tau_{max}]$, defined by the tolerance of the components (Rad et al., 2023).

We think that Arduino boards, especially the Uno R3, are a great (open) hardware platform to introduce the concepts of data acquisition and signal production for the experimental physics (Prayogi et al., 2021). Students are required to build the software for data acquisition in addition to designing the experimental apparatus while considering the hardware's characteristics and the phenomena being studied. Multiple competencies can be learned and gained using a single platform.

CONCLUSION

In summary, using simple and inexpensive equipment, it is possible to explore RC circuits and measure τ, the characteristic time scale. The researchers can create a square-wave generator and a data-gathering system using the Arduino platform and very little programming knowledge. Data processing and visualization, including data fitting to experimental data, can be done on a spreadsheet. Although it is not required, using an oscilloscope will allow students to see the charge-discharge cycle in real-time and modify it by changing the values of the circuit's components. The construction of a fully integrated capacitance measurement system using an Arduino platform, complete with data visualization and no need for external data processing, will be the focus of future studies. As our work indicates, the researchers think the Arduino platform is good hardware for basic laboratory equipment and may be utilized in a range of experiments for teaching and learning.

AUTHOR CONTRIBUTIONS

SP and FS together discussed ideas and conducted experiments. Furthermore, SP, FS, and S compiled a report on the results of the experiments that were carried out.

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